



US009231657B2

(12) **United States Patent**
Vedantham et al.

(10) **Patent No.:** **US 9,231,657 B2**
(45) **Date of Patent:** **Jan. 5, 2016**

(54) **ADAPTIVE SUB-BAND ALGORITHM FOR
POINT-TO-POINT COMMUNICATION IN PLC
NETWORKS**

USPC 370/347, 461, 474
See application file for complete search history.

(71) Applicant: **Texas Instruments Incorporated,**
Dallas, TX (US)

(72) Inventors: **Ramanuja Vedantham**, Allen, TX (US);
Kumaran Vijayasankar, Dallas, TX
(US); **Xiaolin Lu**, Plano, TX (US)

(73) Assignee: **TEXAS INSTRUMENTS
INCORPORATED**, Dallas, TX (US)

(*) Notice: Subject to any disclaimer, the term of this
patent is extended or adjusted under 35
U.S.C. 154(b) by 120 days.

(21) Appl. No.: **13/738,883**

(22) Filed: **Jan. 10, 2013**

(65) **Prior Publication Data**

US 2013/0182719 A1 Jul. 18, 2013

Related U.S. Application Data

(60) Provisional application No. 61/586,216, filed on Jan.
13, 2012.

(51) **Int. Cl.**
H04J 3/24 (2006.01)
H04B 3/54 (2006.01)
H04L 25/02 (2006.01)

(52) **U.S. Cl.**
CPC **H04B 3/542** (2013.01); **H04B 3/54**
(2013.01); **H04L 25/0286** (2013.01)

(58) **Field of Classification Search**
CPC H04B 3/542; H04B 3/544; H04B
2203/5408; H04B 2203/5483; H04B
2203/5466; H04B 3/54; H04B 2203/5416;
H04B 2203/5412

(56) **References Cited**

U.S. PATENT DOCUMENTS

7,173,935 B2 *	2/2007	Lou et al.	370/395.5
7,382,232 B2 *	6/2008	Gidge et al.	340/12.32
7,561,062 B2 *	7/2009	Schleich et al.	340/870.02
7,756,078 B2 *	7/2010	Wyk et al.	370/328
7,802,015 B2 *	9/2010	Cheifot et al.	709/248
7,885,246 B2 *	2/2011	Kuroda et al.	370/347
7,986,718 B2 *	7/2011	Monier	370/509
8,054,821 B2 *	11/2011	Monier et al.	370/350
8,139,614 B2 *	3/2012	Razazian et al.	370/503
8,179,917 B2 *	5/2012	Chan et al.	370/466
8,320,233 B2 *	11/2012	Razazian et al.	370/208
8,325,759 B2 *	12/2012	Hazani et al.	370/466

(Continued)

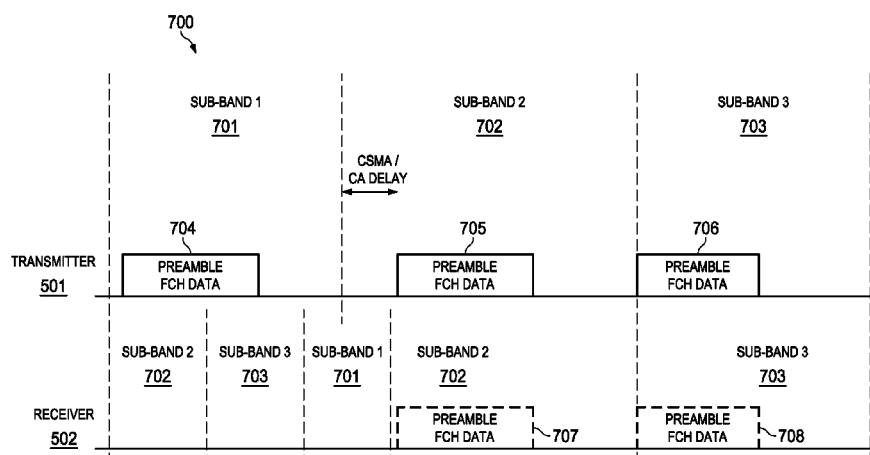
Primary Examiner — Brian O'Connor

(74) *Attorney, Agent, or Firm* — Steven A. Shaw; Frank D.
Cimino

(57) **ABSTRACT**

Embodiments of methods and systems for adaptive sub-band point-to-point communication are presented. In one embodiment a method includes performing functions using a power line communication (PLC) transmitter device. The method may include generating a first data packet having a first adaptive sub-band information set, the first sub-band information set comprising information to be used by a PLC receiver for determining a sub-band hopping pattern. The method may also include transmitting the first data packet on a first PLC sub-band. Additionally, the method may include hopping to a second PLC sub-band, and generating a second data packet having a second adaptive sub-band information set, the second sub-band information set comprising information to be used by the PLC receiver for determine the sub-band hopping pattern. The method may further include transmitting the second data packet on the second PLC sub-band.

17 Claims, 5 Drawing Sheets



(56)

References Cited

U.S. PATENT DOCUMENTS

8,364,326	B2 *	1/2013	Xia et al.	700/295	2003/0038710	A1 *	2/2003	Manis et al.	340/310.01
8,482,402	B2 *	7/2013	Galli et al.	340/539.1	2007/0230377	A1 *	10/2007	Nosaka et al.	370/294
8,619,789	B2 *	12/2013	Hui et al.	370/395.62	2008/0153430	A1 *	6/2008	Yonge, III	455/73
8,780,691	B2 *	7/2014	Razazian et al.	370/208	2010/0074304	A1 *	3/2010	Flammer, III	375/134
8,780,953	B2 *	7/2014	Shaffer et al.	375/132	2010/0322322	A1 *	12/2010	Kodama et al.	375/257
8,879,379	B1 *	11/2014	Razazian et al.	370/208	2012/0218120	A1 *	8/2012	Ree et al.	340/870.02
					2013/0016759	A1 *	1/2013	Hui et al.	375/135
					2013/0181847	A1 *	7/2013	Willig et al.	340/870.03

* cited by examiner

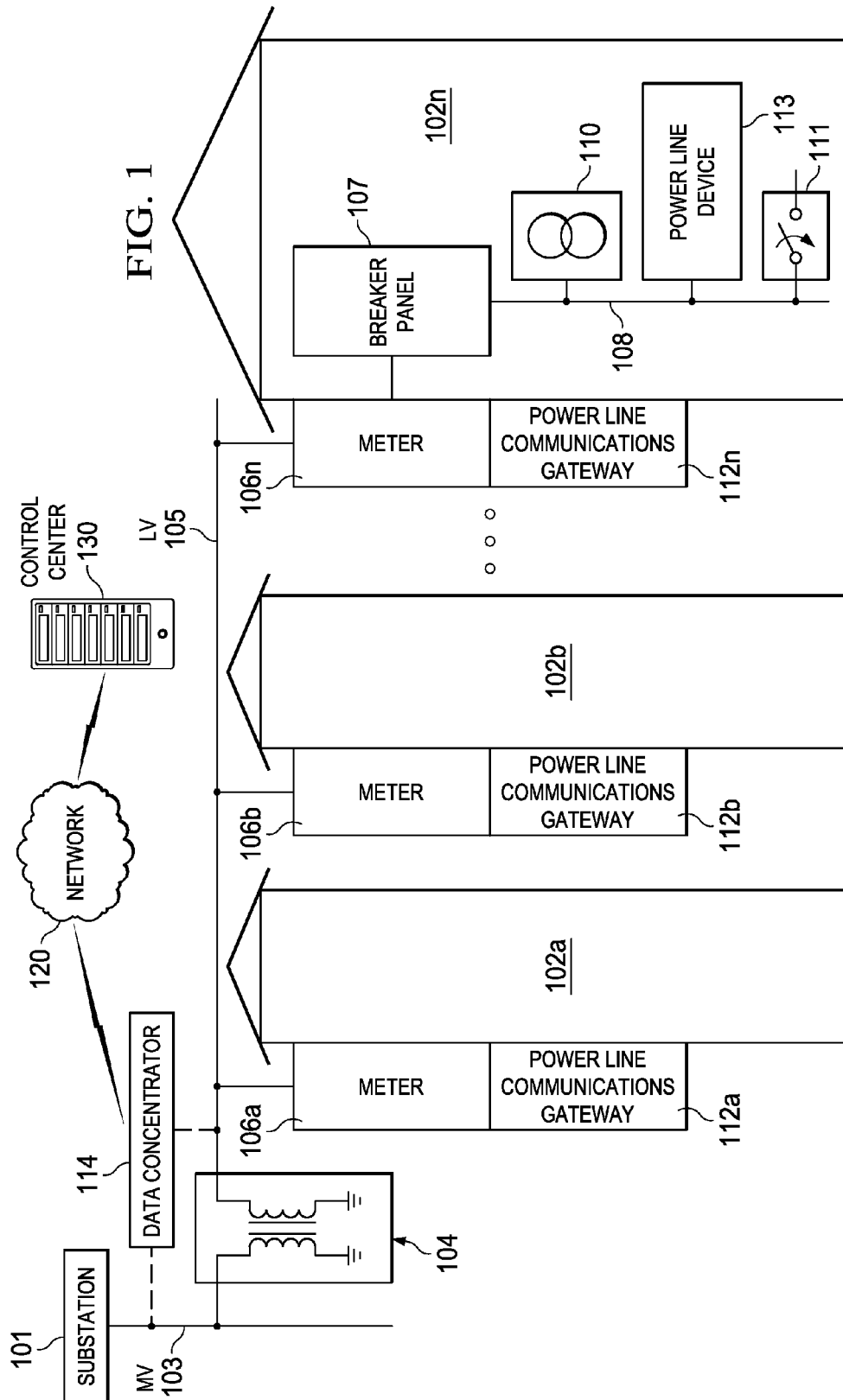


FIG. 2

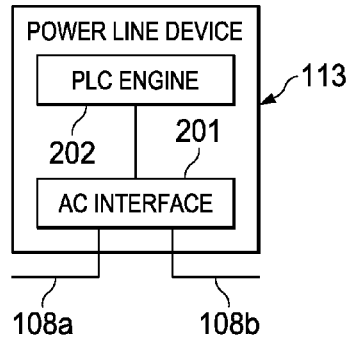


FIG. 3

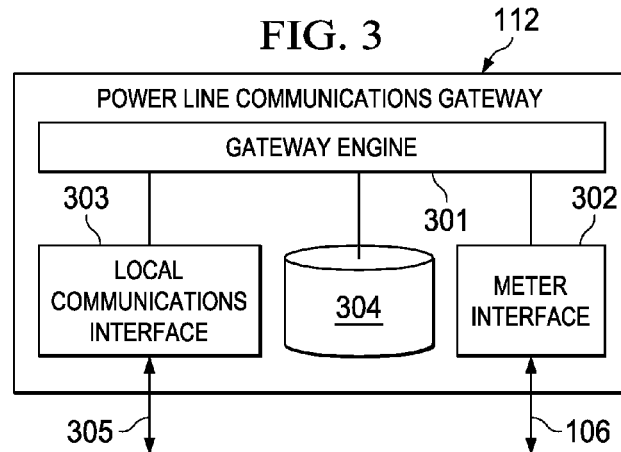
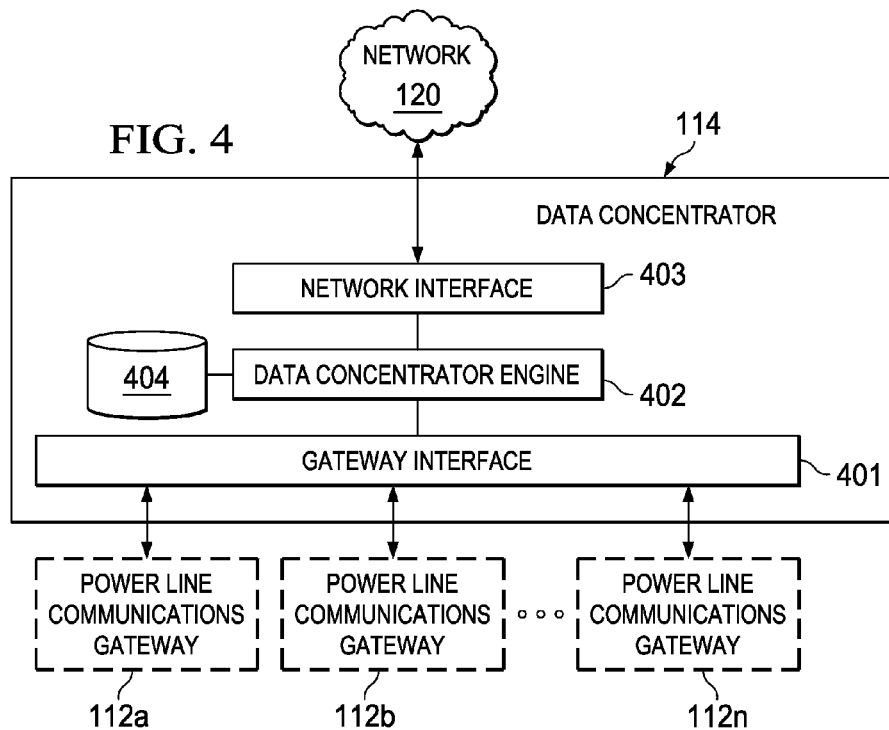


FIG. 4



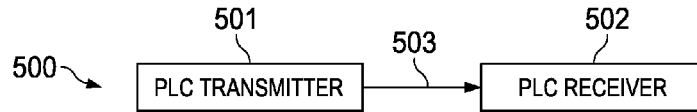


FIG. 5

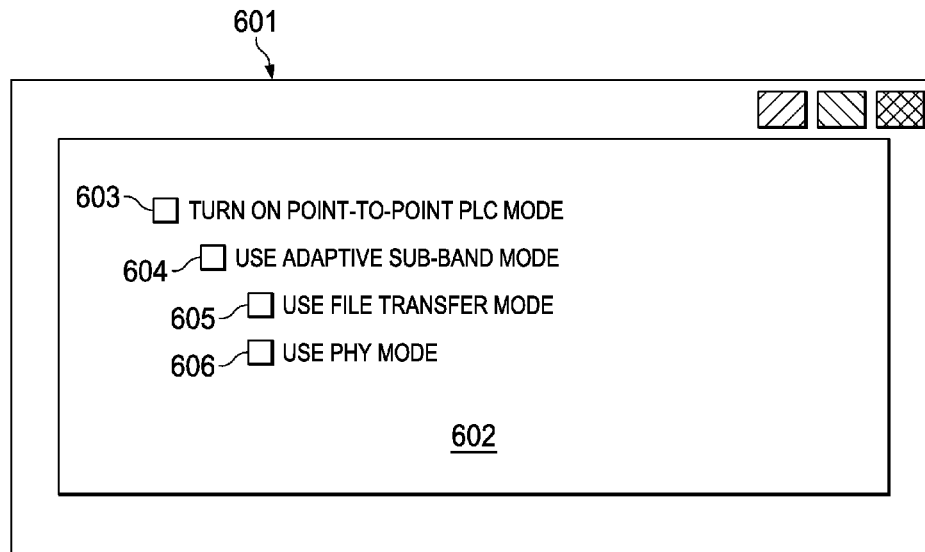


FIG. 6

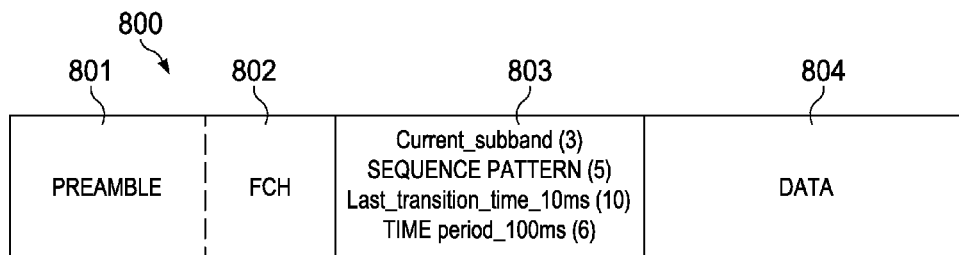


FIG. 8A

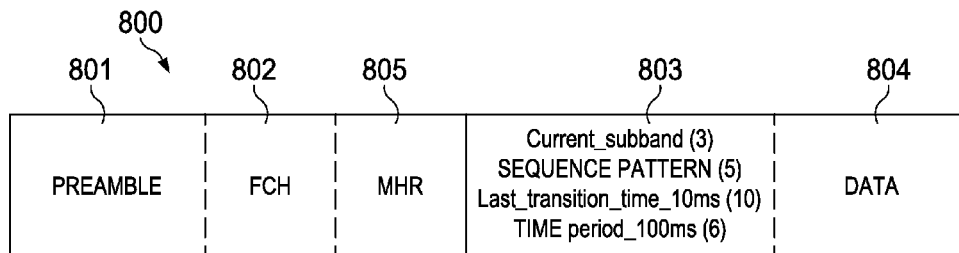


FIG. 8B

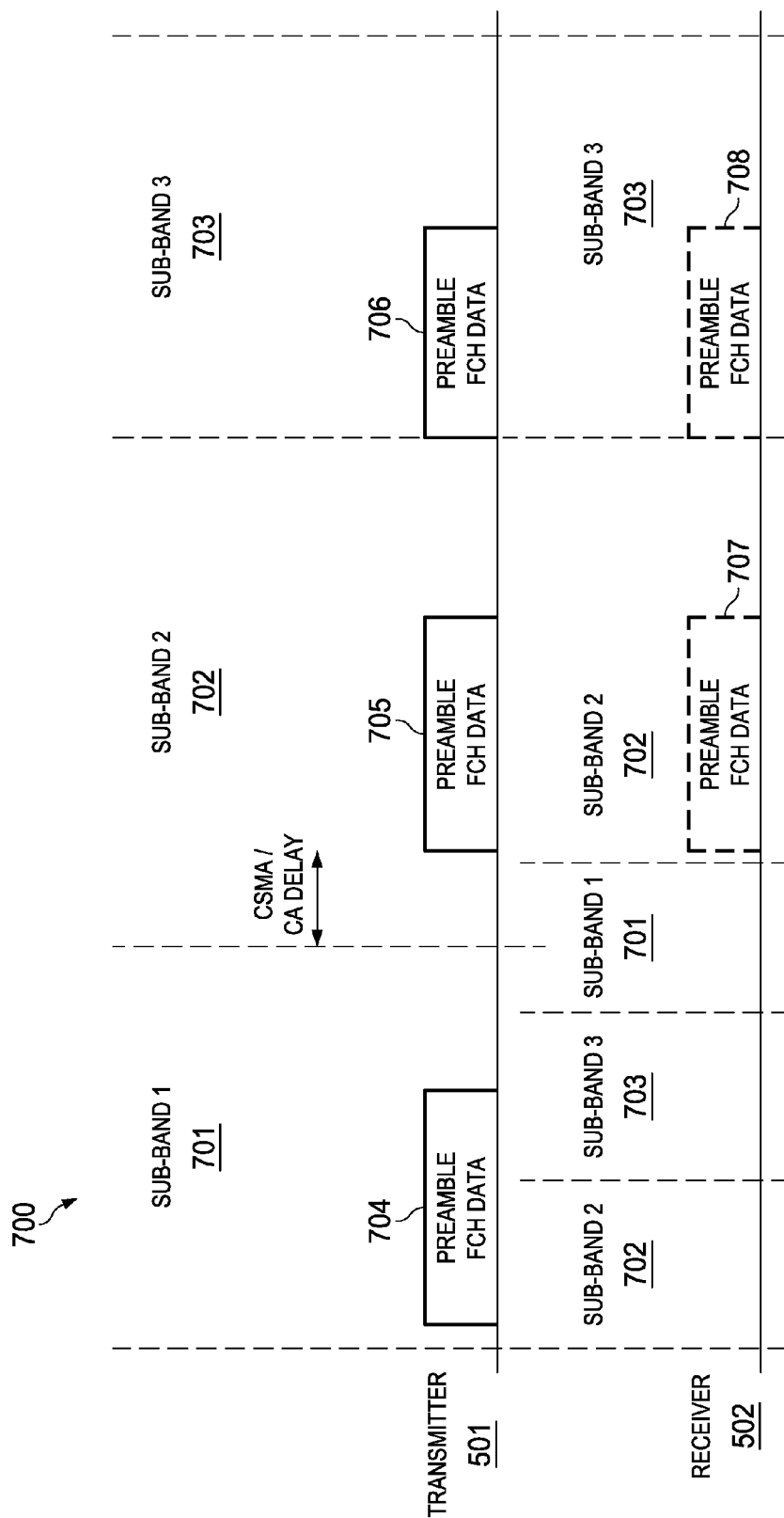


FIG. 7

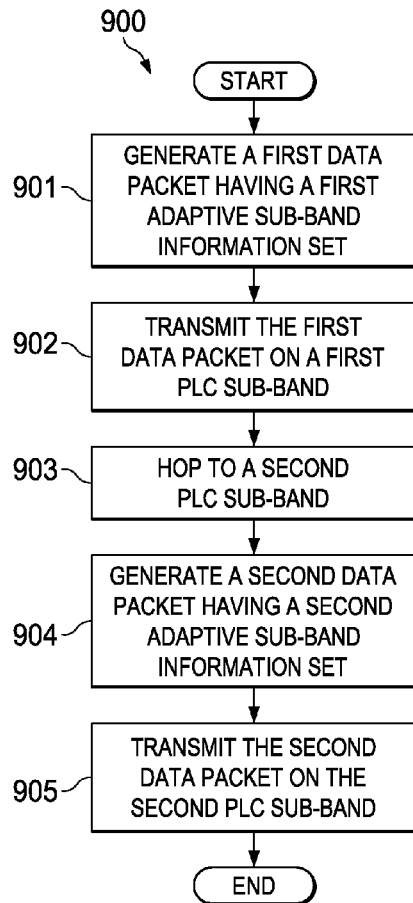


FIG. 9

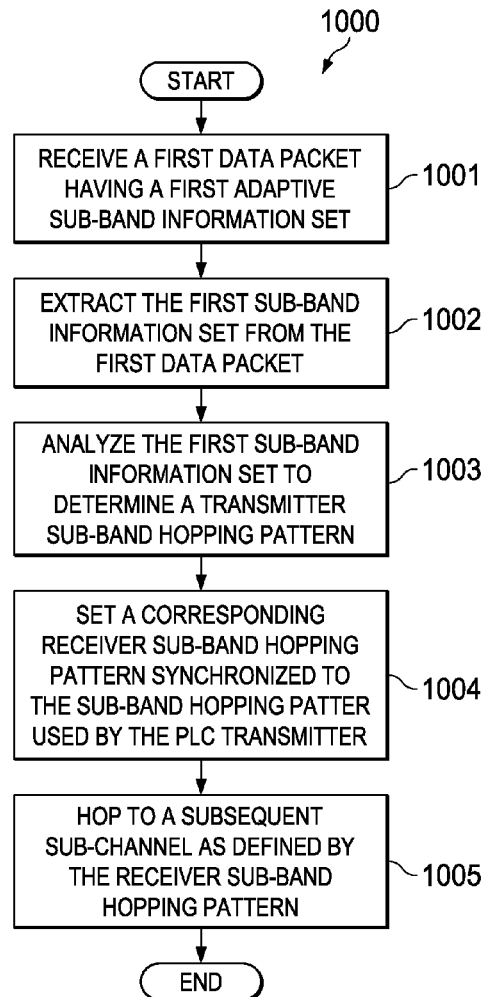


FIG. 10

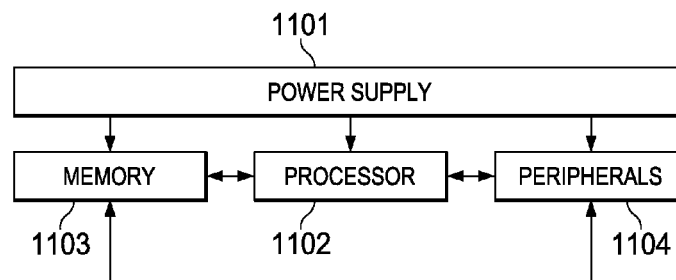


FIG. 11

ADAPTIVE SUB-BAND ALGORITHM FOR POINT-TO-POINT COMMUNICATION IN PLC NETWORKS

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of the filing date of U.S. Provisional Patent Application No. 61/586,216, which is titled "Adaptive Sub-band Algorithm for Point-to-Point Communication in PLC Networks" and was filed on Jan. 13, 2012, the disclosure of which is hereby incorporated by reference herein in its entirety.

TECHNICAL FIELD

Embodiments of the invention are directed, in general, to Power Line Communications (PLC) and, more specifically, to methods for adaptive sub-band point-to-point communication.

BACKGROUND

Power line communications (PLC) include systems for communicating data over the same medium that is also used to transmit electric power to residences, buildings, and other premises, such as wires, power lines, or other conductors. In its simplest terms, PLC modulates communication signals over existing power lines. This enables devices to be networked without introducing any new wires or cables. This capability is extremely attractive across a diverse range of applications that can leverage greater intelligence and efficiency through networking. PLC applications include utility meters, home area networks, lighting, and solar.

Using PLC to communicate with utility meters enable applications such as Automated Meter Reading (AMR) and Automated Meter Infrastructure (AMI) communications without the need to install additional wires. Consumers may also use PLC to connect home electric meters to an energy monitoring device or in-home display monitor their energy consumption and to leverage lower-cost electric pricing based on time-of-day demand.

As the home area network expands to include controlling home appliances for more efficient consumption of energy, OEMs may use PLC to link these devices and the home network. PLC may also support home and industrial automation by integrating intelligence into a wide variety of lighting products to enable functionality such as remote control of lighting, automated activation and deactivation of lights, monitoring of usage to accurately calculate energy costs, and connectivity to the grid.

PLC may also serve as an important enabling technology for the mass deployment of solar equipment by providing a communication channel to solar inverters for monitoring and managing power across the grid by utility companies. While radio frequency (RF) communications have made some progress in solar installations, PLC offers an ideal means for connecting equipment with high reliability and at a low cost on DC or AC lines.

PLC is a generic term for any technology that uses power lines as a communications channel. Various PLC standardization efforts are currently in work around the world. The different standards focus on different performance factors and issues relating to particular applications and operating environments. Two of the most well-known PLC standards are G3 and PRIME. G3 has been approved by the International Telecommunication Union (ITU). IEEE is developing

the IEEE P1901.2 standard that is based on G3. Each PLC standard has its own unique characteristics.

The manner in which PLC systems are implemented depends upon local regulations, characteristics of local power grids, etc. The frequency band available for PLC users depends upon the location of the system. In Europe, PLC bands are defined by the CENELEC (European Committee for Electrotechnical Standardization). The CENELEC-A band (3 kHz-95 kHz) is exclusively for energy providers. The CENELEC-B, C, D bands are open for end user applications, which may include PLC users. Typically, PLC systems operate between 35-90 kHz in the CENELEC A band using 36 tones spaced 1.5675 kHz apart. In the United States, the FCC has conducted emissions requirements that start at 535 kHz and therefore the PLC systems have an FCC band defined from 154-487.5 kHz using 72 tones spaced at 4.6875 kHz apart. In other parts of the world different frequency bands are used, such as the Association of Radio Industries and Businesses (ARIB)-defined band in Japan, which operates at 10-450 kHz, and the Electric Power Research Institute (EPRI)-defined bands in China, which operates at 3-90 kHz.

SUMMARY OF THE INVENTION

Embodiments of methods and systems for adaptive sub-band point-to-point communication are presented. In one embodiment a method includes performing functions using a power line communication (PLC) transmitter device. The method may include generating a first data packet having a first adaptive sub-band information set, the first sub-band information set comprising information to be used by a PLC receiver for determining a sub-band hopping pattern. The method may also include transmitting the first data packet on a first PLC sub-band. Additionally, the method may include hopping to a second PLC sub-band, and generating a second data packet having a second adaptive sub-band information set, the second sub-band information set comprising information to be used by the PLC receiver for determine the sub-band hopping pattern. The method may further include transmitting the second data packet on the second PLC sub-band.

In an embodiment, the method may additionally include receiving a user input for configuring point-to-point PLC communication with the PLC receiver via a graphical user interface (GUI).

In one embodiment, the method includes transmitting the first data packet and transmitting the second data packet are performed according to a File Transfer mode of operation. In such an embodiment, the first adaptive sub-band information set and the second adaptive sub-band information set comprise an adaptive sub-band header in the first data packet and the second data packet respectively.

In another embodiment, the method may include transmitting the first data packet and transmitting the second data packet are performed according to a PHY mode of operation. In such an embodiment, the first adaptive sub-band information set and the second adaptive sub-band information set comprise a portion of the data payload of the first data packet and the second data packet respectively.

In one embodiment, the first adaptive sub-band information set comprises an identifier of the first PLC sub-band. The second adaptive sub-band information set may include an identifier of the second PLC sub-band. The first adaptive sub-band information set and the second adaptive sub-band information set may include information defining a sub-band hopping sequence pattern. The first adaptive sub-band information set and the second adaptive sub-band information set may include a timestamp of a sub-band transition to the first

PLC sub-band and to the second PLC sub-band respectively. The first adaptive sub-band information set and the second adaptive sub-band information set may include information defining a duration of time the transmitter will transmit on the first PLC sub-band and the second PLC sub-band respectively.

In one embodiment, the method includes terminating CSMA/CA delay of transmissions in response to receipt of a data packet from the PLC receiver. In such an embodiment, the method includes fully utilizing the sub-band duration in each of the sub-bands in response to receipt of the data packet from the PLC receiver, wherein the data packet indicates that the PLC receiver is synchronized to the PLC transmitter device.

Another embodiment of a method may be performed by a power line communication (PLC) receiver device. In such an embodiment, the method includes receiving a first data packet having a first adaptive sub-band information set, the first sub-band information set comprising information from a PLC transmitter. The method may further include extracting the first sub-band information set from the first data packet. Additionally, the method may include analyzing the first sub-band information set to determine a transmitter sub-band hopping pattern. The method may also include setting a corresponding receiver sub-band hopping pattern synchronized to the sub-band hopping pattern used by the PLC transmitter. Also, the method may include hopping to a subsequent sub-band as defined by the receiver sub-band hopping pattern.

In such an embodiment, the PLC receiver device may be initially configured to hop sub-bands at an initial hopping rate that is faster than a hopping rate of PLC transmitter. Alternatively, the PLC receiver device may be initially configured to hop sub-bands at an initial hopping rate that is slower than a hopping rate of the PLC transmitter.

An embodiment of a system may include a PLC transmitter device and a PLC receiver device. In one embodiment, the PLC transmitter device may be configured to generate a first data packet having a first adaptive sub-band information set. Additionally, the PLC transmitter device may be configured to transmit the first data packet on a first PLC sub-band, hop to a second PLC sub-band, generate a second data packet having a second adaptive sub-band information set, the second sub-band information set, and transmit the second data packet on the second PLC sub-band. In one embodiment, the PLC receiver device may be configured to receive at least one of the first data packet having the first adaptive sub-band information set or the second data packet having the second adaptive sub-band information set, extract at least one of the first sub-band information set from the first data packet or the second sub-band information set from the second data packet, analyze the at least one of the first sub-band information set or the second sub-band information set to determine a transmitter sub-band hopping pattern, set a corresponding receiver sub-band hopping pattern synchronized to the sub-band hopping pattern used by the PLC transmitter device, and hop to a subsequent sub-band as defined by the receiver sub-band hopping pattern.

In a further embodiment, the PLC transmitter device may transmit the first data packet and the second data packet according to a File Transfer mode of operation. The first adaptive sub-band information set and the second adaptive sub-band information set comprise an adaptive sub-band header in the first data packet and the second data packet respectively.

Alternatively, the PLC transmitter device may transmit the first data packet and the second data packet according to a PHY mode of operation. The first adaptive sub-band infor-

mation set and the second adaptive sub-band information set may include a portion of the data payload of the first data packet and the second data packet respectively.

In one embodiment, the PLC receiver device is initially configured to hop sub-bands at an initial hopping rate that is faster than a hopping rate of PLC transmitter. Alternatively, the PLC receiver device is initially configured to hop sub-bands at an initial hopping rate that is slower than a hopping rate of the PLC transmitter.

BRIEF DESCRIPTION OF THE DRAWINGS

Having thus described the invention in general terms, reference will now be made to the accompanying drawings, wherein:

FIG. 1 is a diagram of a PLC system according to some embodiments.

FIG. 2 is a block diagram of a PLC device or modem according to some embodiments.

FIG. 3 is a block diagram of a PLC gateway according to some embodiments.

FIG. 4 is a block diagram of a PLC data concentrator according to some embodiments.

FIG. 5 is a schematic block diagram illustrating one embodiment of a system configured for point-to-point PLC.

FIG. 6 is diagram illustrating one embodiment of an adaptive sub-band algorithm for use in point-to-point PLC systems.

FIG. 7 is an illustration of one embodiment of a GUI that may be configured for use with the present embodiments.

FIG. 8A is a diagram illustrating one embodiment of an adaptive sub-band packet header configuration for use in PHY testing mode operation.

FIG. 8B is a diagram illustrating one embodiment of an adaptive sub-band packet header configuration for use in a file transfer mode of operation.

FIG. 9 is a schematic flowchart diagram illustrating one embodiment of a method for adaptive sub-band point-to-point communication in PLC networks.

FIG. 10 is a diagram illustrating one embodiment of a method for adaptive sub-band point-to-point communication in PLC networks.

FIG. 11 is a block diagram of an integrated circuit according to some embodiments.

DETAILED DESCRIPTION

The invention now will be described more fully hereinafter with reference to the accompanying drawings. This invention may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. One skilled in the art may be able to use the various embodiments of the invention.

FIG. 1 illustrates a PLC system according to some embodiments. Medium voltage (MV) power lines **103** from substation **101** typically carry voltage in the tens of kilovolts range. Transformer **104** steps the MV power down to low voltage (LV) power on LV lines **105**, carrying voltage in the range of 100-240 VAC. Transformer **104** is typically designed to operate at very low frequencies in the range of 50-60 Hz. Transformer **104** does not typically allow high frequencies, such as signals greater than 100 KHz, to pass between LV lines **105** and MV lines **103**. LV lines **105** feed power to customers via meters **106a-n**, which are typically mounted on the outside of

5

residences **102a-n**. Although referred to as “residences,” premises **102a-n** may include any type of building, facility, electric vehicle charging station, or other location where electric power is received and/or consumed. A breaker panel, such as panel **107**, provides an interface between meter **106n** and electrical wires **108** within residence **102n**. Electrical wires **108** deliver power to outlets **110**, switches **111** and other electric devices within residence **102n**.

The power line topology illustrated in FIG. 1 may be used to deliver high-speed communications to residences **102a-n**. In some implementations, power line communications modems or gateways **112a-n** may be coupled to LV power lines **105** at meter **106a-n**. PLC modems/gateways **112a-n** may be used to transmit and receive data signals over MV/LV lines **103/105**. Such data signals may be used to support metering and power delivery applications (e.g., smart grid applications), communication systems, high speed Internet, telephony, video conferencing, and video delivery, to name a few. By transporting telecommunications and/or data signals over a power transmission network, there is no need to install new cabling to each subscriber **102a-n**. Thus, by using existing electricity distribution systems to carry data signals, significant cost savings are possible.

An illustrative method for transmitting data over power lines may use a carrier signal having a frequency different from that of the power signal. The carrier signal may be modulated by the data, for example, using an OFDM technology or the like described, for example, by the PRIME, G3 or IEEE 1901 standards.

PLC modems or gateways **112a-n** at residences **102a-n** use the MV/LV power grid to carry data signals to and from PLC data concentrator or router **114** without requiring additional wiring. Concentrator **114** may be coupled to either MV line **103** or LV line **105**. Modems or gateways **112a-n** may support applications such as high-speed broadband Internet links, narrowband control applications, low bandwidth data collection applications, or the like. In a home environment, for example, modems or gateways **112a-n** may further enable home and building automation in heat and air conditioning, lighting, and security. Also, PLC modems or gateways **112a-n** may enable AC or DC charging of electric vehicles and other appliances. An example of an AC or DC charger is illustrated as PLC device **113**. Outside the premises, power line communication networks may provide street lighting control and remote power meter data collection.

One or more PLC data concentrators or routers **114** may be coupled to control center **130** (e.g., a utility company) via network **120**. Network **120** may include, for example, an IP-based network, the Internet, a cellular network, a WiFi network, a WiMax network, or the like. As such, control center **130** may be configured to collect power consumption and other types of relevant information from gateway(s) **112** and/or device(s) **113** through concentrator(s) **114**. Additionally or alternatively, control center **130** may be configured to implement smart grid policies and other regulatory or commercial rules by communicating such rules to each gateway(s) **112** and/or device(s) **113** through concentrator(s) **114**.

FIG. 2 is a block diagram of PLC device **113** according to some embodiments. As illustrated, AC interface **201** may be coupled to electrical wires **108a** and **108b** inside of premises **112n** in a manner that allows PLC device **113** to switch the connection between wires **108a** and **108b** off using a switching circuit or the like. In other embodiments, however, AC interface **201** may be connected to a single wire **108** (i.e., without breaking wire **108** into wires **108a** and **108b**) and without providing such switching capabilities. In operation, AC interface **201** may allow PLC engine **202** to receive and

6

transmit PLC signals over wires **108a-b**. In some cases, PLC device **113** may be a PLC modem. Additionally or alternatively, PLC device **113** may be a part of a smart grid device (e.g., an AC or DC charger, a meter, etc.), an appliance, or a control module for other electrical elements located inside or outside of premises **112n** (e.g., street lighting, etc.).

PLC engine **202** may be configured to transmit and/or receive PLC signals over wires **108a** and/or **108b** via AC interface **201** using a particular frequency band. In some embodiments, PLC engine **202** may be configured to transmit OFDM signals, although other types of modulation schemes may be used. As such, PLC engine **202** may include or otherwise be configured to communicate with metrology or monitoring circuits (not shown) that are in turn configured to measure power consumption characteristics of certain devices or appliances via wires **108**, **108a**, and/or **108b**. PLC engine **202** may receive such power consumption information, encode it as one or more PLC signals, and transmit it over wires **108**, **108a**, and/or **108b** to higher-level PLC devices (e.g., PLC gateways **112n**, data aggregators **114**, etc.) for further processing. Conversely, PLC engine **202** may receive instructions and/or other information from such higher-level PLC devices encoded in PLC signals, for example, to allow PLC engine **202** to select a particular frequency band in which to operate.

FIG. 3 is a block diagram of PLC gateway **112** according to some embodiments. As illustrated in this example, gateway engine **301** is coupled to meter interface **302**, local communication interface **304**, and frequency band usage database **304**. Meter interface **302** is coupled to meter **106**, and local communication interface **304** is coupled to one or more of a variety of PLC devices such as, for example, PLC device **113**. Local communication interface **304** may provide a variety of communication protocols such as, for example, ZigBee, Bluetooth, Wi-Fi, Wi-Max, Ethernet, etc., which may enable gateway **112** to communicate with a wide variety of different devices and appliances. In operation, gateway engine **301** may be configured to collect communications from PLC device **113** and/or other devices, as well as meter **106**, and serve as an interface between these various devices and PLC data concentrator **114**. Gateway engine **301** may also be configured to allocate frequency bands to specific devices and/or to provide information to such devices that enable them to self-assign their own operating frequencies.

In some embodiments, PLC gateway **112** may be disposed within or near premises **102n** and serve as a gateway to all PLC communications to and/or from premises **102n**. In other embodiments, however, PLC gateway **112** may be absent and PLC devices **113** (as well as meter **106n** and/or other appliances) may communicate directly with PLC data concentrator **114**. When PLC gateway **112** is present, it may include database **304** with records of frequency bands currently used, for example, by various PLC devices **113** within premises **102n**. An example of such a record may include, for instance, device identification information (e.g., serial number, device ID, etc.), application profile, device class, and/or currently allocated frequency band. As such, gateway engine **301** may use database **305** in assigning, allocating, or otherwise managing frequency bands assigned to its various PLC devices.

FIG. 4 is a block diagram of PLC data concentrator or router **114** according to some embodiments. Gateway interface **401** is coupled to data concentrator engine **402** and may be configured to communicate with one or more PLC gateways **112a-n**. Network interface **403** is also coupled to data concentrator engine **402** and may be configured to communicate with network **120**. In operation, data concentrator engine **402** may be used to collect information and data from

7

multiple gateways **112a-n** before forwarding the data to control center **130**. In cases where PLC gateways **112a-n** are absent, gateway interface **401** may be replaced with a meter and/or device interface (now shown) configured to communicate directly with meters **116a-n**, PLC devices **113**, and/or other appliances. Further, if PLC gateways **112a-n** are absent, frequency usage database **404** may be configured to store records similar to those described above with respect to database **304**.

FIG. 5 is a schematic block diagram illustrating one embodiment of a system **500** configured for point-to-point PLC. The system **500** may include a PLC transmitter **501** and a PLC receiver **502**. For example, a PLC gateway **112** may be configured as the PLC transmitter **501** and a PLC device **113** may be configured as the PLC receiver **502**. Alternatively, the PLC device **113** may be configured as the PLC transmitter **501** and the PLC gateway **112** may be configured as the PLC receiver **502**. In still a further embodiment, the data concentrator **114** may be configured as either the PLC transmitter **501** or the PLC receiver **502** and configured in combination with a PLC gateway **112** or a PLC device **113** in a point-to-point system **500**. In still a further embodiment, a plurality of PLC devices **113** may be configured to communicate directly in a point-to-point PLC system **500** as described in FIG. 5. Additionally, the substation **101** may be configured in a point-to-point system **500** as described above. On of ordinary skill in the art will recognize a variety of suitable configurations for the point-to-point PLC system **500** described in FIG. 5.

FIG. 6 illustrates one embodiment of a GUI **601** that may be configured for use with the present embodiments. The GUI **601** may include a user control panel **602**. The user control panel **602** may include one or more user controls **603-606**. For example, the GUI **601** may include a user control **603** for turning on and/or off point-to-point PLC mode on the transmitter **501** or the receiver **502**. In one embodiment, the user control **603** may be a selectable button, box, or the like. In a further embodiment, the GUI may include a second user control **604** for allowing a user to select adaptive sub-band mode of operation. A fourth user control **605** may allow a user to select a File Transfer mode of operation. A fifth user control **606** may allow a user to select a PHY testing mode of operation. One of ordinary skill in the art will recognize a variety of GUI configurations and arrangements which may be suitable for use with the present embodiments. Although the GUI **601** is presented as one embodiment of a method for configuring the PLC transmitter **501** and/or PLC receiver **502**, one of ordinary skill will recognize alternative methods for configuring these devices.

As illustrated in FIG. 7, the PLC transmitter **501** may be configured to transmit data via a point-to-point connection **503** to the PLC receiver **502**. FIG. 7 is diagram illustrating one embodiment of an adaptive sub-band algorithm **700** for use in point-to-point PLC systems **500**.

In one embodiment, a user may specify that the adaptive sub-band mode of operation using the intermediate GUI **601**. One of the nodes in system **500** is configured to be the PLC transmitter **501** and the other node is configured to be the PLC receiver **502**. The PLC transmitter **501** may have a fixed hopping pattern of the sub-bands **701-703** and transmit packets **704-706** for a fixed duration of time in each of sub-bands **701-703** respectively. The PLC receiver **502** may initially wait for a brief duration of time in each of the sub-bands **704-706** in a time-sliced fashion, and try to lock-in to the transmitter pattern. It will receive the packets **704-706** from the PLC transmitter **501** eventually in at least one of the sub-bands **601-603**. When the receiver **502** receives the first frame, the transmitter **501** would have included the start time

8

for the current sub-band, the time spent in each sub-band and the hopping pattern associated with each of the sub-bands. Therefore, the receiver **502** would have locked on to the transmitter even if it has received a single frame. The details of the frame format are discussed in below in FIGS. **8A-B**.

For illustrative purposes, three sub-bands have been shown in FIG. 7. For simplification of explanation, assume that the transmitter spends eight second each in every sub-band **701-703**. During the eight second time slot, the PLC transmitter **501** sends as many frames as possible using either CSMA/CA (file transfer mode of p2p operation) or using the PHY testing mode (RAMP data). The PLC transmitter **501** includes in each frame an adaptive sub-band information set, which includes the start of the current sub-band, the hopping sequence and the time elapsed from the last sub-band transition along with the time period spent in each sub-band.

Further assuming that the PLC receiver **502** spends approximately two seconds in each of the sub-bands in a cyclic repetitive fashion. In this case the receiver would have spent at least a portion of time, for example two seconds or more, in each of the three sub-bands **701-703**. If this is one of the desired sub-bands in terms of PHY connectivity, the receiver **502** will be able to lock on to at least one packet received in this sub-band. In such an embodiment, even the reception of a single packet will allow the receiver **502** to determine the hopping pattern used by the transmitter **501** and the duration spent in each of the sub-bands. Thus, the hopping pattern of the receiver **502** may be synchronized with the hopping pattern of the transmitter **501**.

The worst case delay for the receiver to synchronize to the transmitter pattern will be one cycle duration spent by the transmitter across all sub-bands, which corresponds to twenty-four seconds in the above example. After the receiver has locked on to the transmitter pattern, it can at least listen to all transmissions in the sub-band used for the initial synchronization, and can correct any clock drifts. If the test is performed for long enough duration, for example greater than twenty minutes, the initial synchronization period will be small, for example less than two percent, and the performance results will be representative of the performance observed in each sub-band.

In another embodiment, the receiver **502** may transition between sub-bands much slower than the transmitter **501**. For example, the inverse of the example described above may be implemented, where the transmitter **501** spends two seconds in each sub-band **701-703** and the receiver **502** spends eight seconds in each sub-band **701-703**. In such an embodiment, the receiver **502** may be able to lock on to the hopping pattern upon receipt of the first data packet **704** received from the transmitter **501**.

To enable or disable the adaptive sub-band mode, the user may be allowed to make a selection, such as checking a box or not in the intermediate GUI **601**. If the box **604** is checked for a transmitter **501**, the transmitter **501** may include the additional header format described below. Similarly, at the receiver **502**, if the box **604** is checked, the first three bytes following the PHY FCH or MHR (depending on the mode of operation), may be treated as the adaptive sub-band header as shown in FIGS. **8A-B**.

The transmitter **501** may embed the adaptive sub-band information set **803** in the packet **800** as shown in FIGS. **8A-B**. The current sub-band indicates the current sub-band used for the transmission. The sequence pattern indicates the pattern of sub-bands to follow using the current sub-band as the reference. In the example with three sub-bands, if the transmitter **501** is operating in the second sub-band **702**, the number of possibilities for different patterns with the second

sub-band **702** as reference is $2P1=2$. Similarly, if there are four sub-bands, the number of possibilities will be at most $3P1=6$. The number of sub-bands may be limited, depending on the number of bits allocated for the sequence pattern. For example, if five bits are allocated, then the number patterns may be limited to five sub-bands. In addition to the sub-band and sequence pattern information, the transmitter **501** may include the last transition time from the previous sub-band. In one embodiment, the last transmission time may be recorded at a granularity of 10s of milliseconds (ms). Similarly, the transmitter **501** may also include the time period in 100s of ms spent on each sub-band.

FIG. **8A** is a diagram illustrating one embodiment of an adaptive sub-band packet configuration for use in PHY testing mode operation. For the PHY testing mode, as indicated in FIG. **8A**, there is no MAC header or MAC CRC **16**. The receiver PHY may perform Bit Error Rate (BER) checks based on the byte pattern received. Since the BER for the PHY testing mode will be affected if we were to include the adaptive sub-band information set in the header the information set may be included after the PHY FCH for this mode of operation.

The receiver **502** upon receiving the adaptive sub-band information set and the RAMP data information will parse the payload to separate the adaptive sub-band information set from the RAMP data. In one embodiment, the adaptive sub-band information set may comprise the first three bytes of the payload data.

FIG. **8B** is a diagram illustrating one embodiment of an adaptive sub-band packet header configuration for use in a file transfer (FTP) mode of operation. In this embodiment, FTP is used at the higher layers, and the MHR and the CRC **16** are present in the MAC PDU created at the transmitter **501**. Therefore, the adaptive sub-band information set may be added after the MHR in this embodiment. The PHY may perform the CRC **16** verification either including the adaptive sub-band information set or using the remaining bytes. In this case, CSMA/CA may be performed. This mode may not be useful if TCP is used and if the network exhibits asymmetric connectivity when using the sub-bands since the ACK sent in the reverse direction may not reach the transmitter. In such an embodiment, CSMA/CA may be terminated upon receipt of a response packet from the receiver **502** and a determination that hop synchronization has been achieved.

FIG. **9** is a schematic flowchart diagram illustrating one embodiment of a method for adaptive sub-band point-to-point communication in PLC networks. In one embodiment, the method **900** starts when the PLC transmitter **501** generates **901** a first data packet **704** having a first adaptive sub-band information set **803**. The PLC transmitter **501** may then transmit **902** the first data packet **704** on the first PLC sub-band **701**. In one embodiment, the PLC transmitter **501** may transmit multiple copies of the first data packet **704** on the first sub-band **701**. Next, at a designated time, the PLC transmitter hops **903** to a second PLC sub-band **702**. The PLC transmitter **501** then generates **904** a second data packet **705** having a second adaptive sub-band information set **803** and transmits **905** the second data packet **705** on the second PLC sub-band **702**.

FIG. **10** is illustrating one embodiment of a method **1000** for adaptive sub-band point-to-point communication in PLC networks. In one embodiment, the PLC receiver **502** receives **1001** a first data packet **704** having a first adaptive sub-band data set **803** from a PLC transmitter **501**. The PLC receiver **502** then extracts **1002** the first adaptive sub-band information set **803** from the first data packet **704**. The receiver **502** may then analyze **1003** the first adaptive sub-band informa-

tion set to determine a sub-band hopping pattern of the transmitter **501**. The receiver **502** then set **1004** a corresponding receiver sub-band hopping pattern which is synchronized to the sub-band hopping pattern used by the PLC transmitter **501**. The receiver **502** may then hop **1005** to a subsequent sub-band as defined by the receiver sub-band hopping pattern.

FIG. **11** is a block diagram of a circuit for implementing adaptive sub-band point-to-point communication according to some embodiments. In some cases, one or more of the devices and/or apparatuses shown in FIGS. **1-4** may be implemented as shown in FIG. **10**. In some embodiments, processor **1102** may be a digital signal processor (DSP), an application specific integrated circuit (ASIC), a system-on-chip (SoC) circuit, a field-programmable gate array (FPGA), a microprocessor, a microcontroller, or the like. Processor **1102** is coupled to one or more peripherals **1104** and external memory **1103**. In some cases, external memory **1103** may be used to store and/or maintain databases **304** and/or **404** shown in FIGS. **3** and **4**. Further, processor **1102** may include a driver for communicating signals to external memory **1103** and another driver for communicating signals to peripherals **1104**. Power supply **1101** provides supply voltages to processor **1102** as well as one or more supply voltages to memory **1103** and/or peripherals **1104**. In some embodiments, more than one instance of processor **1102** may be included (and more than one external memory **1103** may be included as well).

Peripherals **1104** may include any desired circuitry, depending on the type of PLC system. For example, in an embodiment, peripherals **1104** may implement local communication interface **303** and include devices for various types of wireless communication, such as Wi-Fi, ZigBee, Bluetooth, cellular, global positioning system, etc. Peripherals **1104** may also include additional storage, including RAM storage, solid-state storage, or disk storage. In some cases, peripherals **1104** may include user interface devices such as a display screen, including touch display screens or multi-touch display screens, keyboard or other input devices, microphones, speakers, etc.

External memory **1103** may include any type of memory. For example, external memory **1103** may include SRAM, nonvolatile RAM (NVRAM, such as "flash" memory), and/or dynamic RAM (DRAM) such as synchronous DRAM (SDRAM), double data rate (DDR, DDR2, DDR3, etc.) SDRAM, DRAM, etc. External memory **1103** may include one or more memory modules to which the memory devices are mounted, such as single inline memory modules (SIMMs), dual inline memory modules (DIMMs), etc.

It will be understood that in various embodiments, the modules shown in FIGS. **2-4** may represent sets of software routines, logic functions, and/or data structures that are configured to perform specified operations. Although these modules are shown as distinct logical blocks, in other embodiments at least some of the operations performed by these modules may be combined in to fewer blocks. Conversely, any given one of the modules shown in FIGS. **2-4** may be implemented such that its operations are divided among two or more logical blocks. Moreover, although shown with a particular configuration, in other embodiments these various modules may be rearranged in other suitable ways.

Many of the operations described herein may be implemented in hardware, software, and/or firmware, and/or any combination thereof. When implemented in software, code segments perform the necessary tasks or operations. The program or code segments may be stored in a processor-readable, computer-readable, or machine-readable medium. The pro-

11

cessor-readable, computer-readable, or machine-readable medium may include any device or medium that can store or transfer information. Examples of such a processor-readable medium include an electronic circuit, a semiconductor memory device, a flash memory, a ROM, an erasable ROM (EROM), a floppy diskette, a compact disk, an optical disk, a hard disk, a fiber optic medium, etc.

Software code segments may be stored in any volatile or non-volatile storage device, such as a hard drive, flash memory, solid state memory, optical disk, CD, DVD, computer program product, or other memory device, that provides tangible computer-readable or machine-readable storage for a processor or a middleware container service. In other embodiments, the memory may be a virtualization of several physical storage devices, wherein the physical storage devices are of the same or different kinds. The code segments may be downloaded or transferred from storage to a processor or container via an internal bus, another computer network, such as the Internet or an intranet, or via other wired or wireless networks.

Many modifications and other embodiments of the invention(s) will come to mind to one skilled in the art to which the invention(s) pertain having the benefit of the teachings presented in the foregoing descriptions, and the associated drawings. Therefore, it is to be understood that the invention(s) are not to be limited to the specific embodiments disclosed. Although specific terms are employed herein, they are used in a generic and descriptive sense only and not for purposes of limitation.

What is claimed is:

1. A method comprising:

performing, by a power line communication (PLC) transmitter device,
generating a first data packet having a first adaptive sub-band information set, the first sub-band information set comprising information to be used by a PLC receiver for determining a sub-band hopping pattern;
transmitting the first data packet on a first PLC sub-band;
hopping to a second PLC sub-band;
generating a second data packet having a second adaptive sub-band information set, the second sub-band information set comprising information to be used by the PLC receiver for determine the sub-band hopping pattern including an identifier of at least one of the PLC sub-bands; and
transmitting the second data packet on the second PLC sub-band.

2. The method of claim 1, further comprising receiving a user input for configuring point-to-point PLC communication with the PLC receiver via a graphical user interface (GUI).

3. The method of claim 1, wherein transmitting the first data packet and transmitting the second data packet are performed according to a File Transfer mode of operation.

4. The method of claim 2, wherein the first adaptive sub-band information set and the second adaptive sub-band information set comprise an adaptive sub-band header in the first data packet and the second data packet respectively.

5. The method of claim 1, wherein transmitting the first data packet and transmitting the second data packet are performed according to a PHY mode of operation.

6. The method of claim 5, wherein the first adaptive sub-band information set and the second adaptive sub-band information set comprise a portion of the data payload of the first data packet and the second data packet respectively.

12

7. The method of claim 1, wherein the first adaptive sub-band information set comprises an identifier of the first PLC sub-band.

8. The method of claim 1, wherein the second adaptive sub-band information set comprises an identifier of the second PLC sub-band.

9. The method of claim 1, wherein the first adaptive sub-band information set and the second adaptive sub-band information set comprises information defining a sub-band hopping sequence pattern.

10. The method of claim 1, wherein the first adaptive sub-band information set and the second adaptive sub-band information set comprise a timestamp of a sub-band transition to the first PLC sub-band and to the second PLC sub-band respectively.

11. The method of claim 1, wherein the first adaptive sub-band information set and the second adaptive sub-band information set comprises information defining a duration of time the transmitter will transmit on the first PLC sub-band and the second PLC sub-band respectively.

12. The method of claim 1, further comprising terminating CSMA/CA delay of transmissions in response to receipt of a data packet from the PLC receiver.

13. The method of claim 12, further comprising fully utilizing the sub-band duration in each of the sub-bands in response to receipt of the data packet from the PLC receiver, wherein the data packet indicates that the PLC receiver is synchronized to the PLC transmitter device.

14. A system comprising:

a power line communication (PLC) transmitter device configured to:

generate a first data packet having a first adaptive sub-band information set;
transmit the first data packet on a first PLC sub-band;
hop to a second PLC sub-band;
generate a second data packet having a second adaptive sub-band information set, the second sub-band information set; and
transmit the second data packet on the second PLC sub-band; and

a PLC receiver device communicatively coupled to the PLC transmitter device, the PLC receiver device configured to:

receive at least one of the first data packet having the first adaptive sub-band information set or the second data packet having the second adaptive sub-band information set;
extract at least one of the first sub-band information set from the first data packet or the second sub-band information set from the second data packet;
analyze the at least one of the first sub-band information set or the second sub-band information set to determine a transmitter sub-band hopping pattern;
set a corresponding receiver sub-band hopping pattern synchronized to the sub-band hopping pattern used by the PLC transmitter device; and
hop to a subsequent sub-band as defined by the receiver sub-band hopping pattern.

15. The system of claim 14, wherein the first adaptive sub-band information set and the second adaptive sub-band information set comprise an adaptive sub-band header in the first data packet and the second data packet respectively.

13

16. The system of claim **14**, wherein the PLC transmitter device is configured to transmit the first data packet and the second data packet according to a PHY mode of operation.

17. The system of claim **16**, wherein the first adaptive sub-band information set and the second adaptive sub-band information set comprise a portion of the data payload of the first data packet and the second data packet respectively.

* * * * *

14